AD NUMBER
AD826303
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; JAN 1968. Other requests shall be referred to Arnold Engineering Development Center, Arnold AFB, TN.**
AUTHORITY
AEDC ltr 9 Jan 1991

AEDC-TR-67-268

cy. 6

TUNNEL E WITH MAGNETIC MODEL SUPPORT SYSTEM - BASIC CONCEPT AND INITIAL DESIGN

J. M. Langford

ARO, Inc.

Supporting Organization

Advanced Research Projects Agency
ARPA Order No. 988

January 1968

VON KÁRMÁN GAS DYNAMICS FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

TUNNEL E WITH MAGNETIC MODEL SUPPORT SYSTEM - BASIC CONCEPT AND INITIAL DESIGN

J. M. Langford

ARO, Inc.

FOREWORD

The work reported herein was sponsored by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under System 920F, Project 0988. It was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by 1st Lt R. L. Hurlburt under Contract AF40(600)-1200.

The work includes the basic concept and initial design of the modified Tunnel E with magnetic model support system being accomplished by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates). The work covers the time period from March, 1967 to October 31, 1967, under ARO Project No. VE4721. The manuscript was submitted for publication on November 17, 1967.

The author wishes to acknowledge the suggestions and assistance by personnel from the von Kármán Gas Dynamics Facility (VKF) Instrumentation, Hypersonic, and Mechanical Branches; and in particular Messrs. J. C. Sivells and L. Trimmer for the aerodynamic aspects; and Messrs. A. Cortner and M. D. Brown for the magnetic model support system.

This technical report has been reviewed and is approved.

Donald H. Meyer
Major, USAF
AF Representative, VKF
Directorate of Test

Leonard T. Glaser
Colonel, USAF
Director of Test

ABSTRACT

This report discusses the addition of the existing magnetic model suspension system to the 12- by 12-in. hypersonic Tunnel E at Arnold Engineering Development Center. The addition requires an unusually long test section for studying undisturbed model wake. With the magnetic suspension system, the model can be positioned in any axial direction, and the model angle of incidence can be changed in either positive or negative direction. The proposed model positioning sensor system will consist of a gamma or X-ray source and ion detectors that will allow the model position to be controlled without need for optical ports in the tunnel wall. The instrumentation for and overall test capabilities with this magnetic suspension system in Tunnel E are discussed, and proposals for future improvements in the capabilities of the system are made.

CONTENTS

APPENDIX
Illustrations

SECTION I
INTRODUCTION

Experimental studies of re-entry vehicle wakes are urgently needed in support of discrimination and anti-ballistic missile systems which are being developed for ARPA under Project Defender. Whereas far-wake studies can be conducted in aeroballistic ranges, the probing of the base flow and near-wake region is not accessible to the range technique, and the only available experimental method capable of acquisition of the desired information (which bears on the development of the far wake) is that of magnetic model suspension in a hypersonic wind tunnel which allow measurements free of support interference.

This project will accomplish adaptation of the existing AEDC-VKF Tunnel E (Gas Dynamic Wind Tunnel, Hypersonic (E)) to the existing VKF magnetic model suspension system for operation at Mach 8. The basic concept of the completed modification, as shown in Fig. 1, is one which will allow the model to be moved fore and aft in the tunnel and pitched to small angles of attack; the schlieren and probing systems will remain at fixed stations near the downstream end of the nozzle. The design of the modification of Tunnel E was 90-percent complete as of October 1, 1967. Equipment for which all shop drawings are complete is either in the process of being fabricated or scheduled for fabrication.

SECTION II
TUNNEL E

The existing Tunnel E, as described in Ref. 1, is a 12- by 12-in. intermittent hypersonic wind tunnel with a Mach number range of 5 to 8. The high pressure air storage system and the vacuum system provide the necessary pressure ratio across the wind tunnel. The air is supplied from a 7550-cu-ft, 4000-psia storage tank. The tank is supplied by two reciprocating compressors that have a maximum flow capability of 6 lb/sec. The vacuum is provided by a 200,000-cu-ft spherical reservior that can be evacuated with sliding-vane-type vacuum pumps to a pressure of 0.1 psia. Provisions are available for placing the VKF main compressor plant on the sphere for continuous evacuation. Air temperatures up to 940°F, adequate to prevent liquefaction of the air at Mach 8 in the test section, are obtained from an electric-resistance-type heater. The power input to the heater is controlled by liquid rheostat. The present capabilities of Tunnel E are shown in Fig. 2 in terms of free-stream unit Reynolds number. Modifications to the electric heater would permit extending the range to a Mach number of 10. These capabilities will be maintained when the tunnel is modified to accept the magnetic suspension system, although only a Mach 8 nozzle is being planned for initial operation. Additional nozzles and other modifications can be made later to take full advantage of the air supply system.

SECTION III
NOZZLE AND TEST SECTION

The existing Mach number range is achieved by using a two-dimensional nozzle in which the top and bottom walls are formed by contoured throat blocks which can be rotated and by flexible plates which are adjusted by a total of 12 screw jacks to form the contours required for uniform flow in the test section. For the magnetic model suspension system, this nozzle will be replaced by an axisymmetric contoured nozzle (Fig. 1) machined to produce a single Mach number, initially Mach 8. A nozzle with an exit diameter of 13.25 in. is compatible with the air supply and the existing magnetic model suspension system. The tunnel is designed primarily for the purpose of studying the aerodynamic properties of wakes up to at least 10 model base diameters downstream of the model. This imposes the extremely severe requirement that the flow be uniform over a distance of approximately four tunnel exit diameters. The over-all nozzle length is 133 in. measured from the stilling chamber to the test section exit. The contours of the nozzle were obtained essentially as described in Ref. 2, modified by specifying a Mach number distribution along the axis from the throat to the inflection point as well as downstream of the inflection point. The Mach number distribution at the throat is compatible with the throat radius of curvature according to Ref. 3. The Mach number distributions along the axis and along the inviscid nozzle wall are shown in Fig. 3. Provisions in the magnetic model support will allow positioning of the model base from station 85 to station 125. Two windows will be mounted on either side of the downstream portion of the test section with their centerlines at stations 115 and 125. With the exception of the throat section, the nozzle will be fabricated from aluminum and the entire nozzle will be water cooled to maintain dimensional stability. To ensure a minimum amount of disturbance to the flow in the test region, only two joints, at stations 15 and 33, are incorporated in the mechanical design.

The 40-in. axial movement of the model was based upon some preliminary calculations of the approximate location of the reflected bow shock of typical models as shown in Fig. 4 for a sharp 10-deg half-angle cone and in Fig. 5 for a hemisphere-nosed cylinder (the latter based upon Ref. 4).

Some preliminary estimates were made on where transition can be expected on the model or in its wake according to Refs. 5 and 6. As shown in Fig. 6, at the maximum Reynolds number capability of the tunnel, natural transition can be expected near the base of a 4-in.-diam, 10-deg half-angle sharp cone. As the Reynolds number is reduced by lowering the unit Reynolds number or by decreasing the model size, transition moves off of the model and into the wake. The influence of model wall temperature on transition location was not taken into account for these estimates inasmuch as the data from Ref. 5 were obtained with a model wall temperature below one-tenth of recovery temperature and the data from Ref. 6 were obtained with a model wall temperature on the order of one-half the recovery temperature.

SECTION IV
MAGNETIC MODEL SUPPORT SYSTEM

The magnetic model suspension system as described in Ref. 7 is a feedback control servo-system where the aerodynamic test model is held in the wind tunnel by magnetic forces. Four electromagnets mounted in a "V" configuration are used to counteract forces in the vertical and lateral directions, and an air-core solenoid is used to counteract forces in the axial direction. The electric currents that generate the magnetic forces are controlled by the position of the model. For further discussion, the magnetic model suspension system can be divided into four subsystems: (1) the model position detection system, (2) the control and power amplifiers, (3) the electromagnet components, and (4) the model.

4.1 DETECTION SYSTEM

The function of the detection system is to provide an electrical signal that is proportional to the position of the model inside the wind tunnel. In the prototype system five light beams and five photodiodes are used to detect movements of the model. Each light beam intersects a portion of the model in such a manner that five degrees of movement can be resolved.

In an operating tunnel a light beam detection system would necessitate the use of windows or ports in the tunnel wall which could cause flow disturbances in the wake and also limit the versatility of the support system with respect to positioning the model inside the tunnel. A detection system capable of viewing the model through the tunnel walls would provide an aerodynamically clean tunnel as well as a more versatile support system. Since the tunnel walls are constructed from aluminum with a water-cooling channel, a detection system utilizing the penetrating characteristics of high energy photons such as gamma rays or X-rays would be most desirable. In view of the relative mass attenuation coefficients of aluminum (walls) and iron (model), photons in the 60- to 80-Kev energy region are optimum for such a detection system. Radiation in this energy region can be obtained from either nuclear sources or X-ray tubes. However, in view of the source intensity required to provide the desired signal-to-noise ratio and the problems of shielding a nuclear source when the system is not in operation, as well as when in operation, the X-ray tube is considered a more desirable source.

Although preliminary calculations and investigations indicate that an X-ray detection system is quite feasible, one has never been designed and fabricated for such an application as this. With this thought in mind, a contract is being negotiated for the development of a single channel prototype. Based on successful operation of the prototype, a complete system incorporating the prototype and four other channels will be purchased.

4.2 CONTROL AND POWER AMPLIFIERS

Since the position of the model in a magnetic field is basically unstable, an amplifier having specific characteristics is required to provide system stability. The five control amplifiers are constructed from basic solid-state operational amplifier building blocks.

The power amplifiers provide the driving current for the magnetic components. Four of these amplifiers are high-voltage, low-current amplifiers using thyratrons as the active elements. The drag solenoid power amplifier is of the low-voltage, high-current type using silicon-controlled rectifiers as the active elements.

4.3 ELECTROMAGNET COMPONENTS

The lift system consists of four sets of coils, two sets mounted on each of two horseshoe-type iron cores with the horseshoes aligned with the tunnel axis. These four electromagnets provide magnetic forces to counteract lift and lateral forces and pitching and yawing moments. The lift coils are cooled by convection and thereby limit the run time to approximately 20 minutes before overheating occurs.

A new drag solenoid, consisting of hollow copper tubing wound in the form of an annulus around the tunnel, is being fabricated. This solenoid will provide the required reactions to the drag forces. The high power used in the drag solenoid requires that it be cooled by water.

4.4 MODEL LOAD CAPABILITIES

Since the resultant of gravitational and aerodynamic forces is to be counteracted by magnetic forces, the model must be constructed, at least in part, from a magnetic material such as soft iron or mild steel. The maximum magnetic forces, thus the limit of the aerodynamic forces, for a fixed coil configuration and given power amplifier depend primarily on the volume of the magnetic material and the distance from the coils. The lift forces are limited by the magnetic volume of the model since the distance to the lift coils is relatively constant. Drag forces are limited by model volume as well as model length.

Anticipated maximum load capabilities of the system are given for two types of models and three model sizes:

1. Model - Cylinder

   Length - 10.5 in.
   Diameter - 2 in.
   Drag Force* - 36 lb
   Lift Force** - 12 lb
   Weight - 6.87 lb

2. Model - 10-deg Half-Angle Cone

   Base Diameter - 4 in.
   Drag Force* - 12 lb
   Lift Force** - 8.5 lb
   Weight - 5.20 lb

3. Model - 10-deg Half-Angle Cone

   Base Diameter - 2 in.
   Drag Force* - 1.87 lb
   Lift Force** - 0.75 lb
   Weight - 1.00 lb

---

* Drag force quoted is based on anticipated performance of new drag solenoid.

** Lift force quoted is downward and in addition to the model weight.

SECTION V
TESTING CAPABILITIES

5.1 PROBING

Measurements of pressure and temperature in the wake will be accomplished with probes mounted on a probe support. The probe support will accept a variety of probe tips and rakes that can be positioned over a 10-1/4-in. stroke in the vertical plane within ±0.004 in. Manual adjustments will be available for precise location of the probe along the tunnel axis. Model position relative to the probe will be obtained by the axial movement of the magnetic support sensing system and model. The maximum movement available is 40 in. and is shown in Fig. 1. Nominally the downstream limit of the model base is the center of the downstream window, station 125.

Pressure and temperature measuring instrumentation is available with a capability of measuring pressure within ±0.0002 psi and temperature within the standard for Chromel®-Alumel® thermocouples.

5.2 MODEL ANGLE RANGE

The change of model angle of incidence will be accomplished by moving the upstream model positioning sensors to allow the nose of the model to be positioned either above or below the centerline, as shown in Fig. 7. The downstream model positioning sensors are not changed which allows the model to pitch about its base. A maximum movement will be provided that will allow a ±10-deg change of model angle of incidence. Adjustments for model alignment and model size will be available for each positioning sensor.

The actual angle of attack to which a model may be pitched may be limited to less than the ±10 deg available. In a positive (nose-up) direction, the maximum angle will be reached when the lift is equal to the model weight since the required magnetic restraint becomes zero. In a negative direction, the limit is the maximum available magnetic restraint. The above limits are functions of the model size and shape and dynamic pressure in the wind tunnel, as illustrated in Fig. 8 for Model 2 of Section 4.4. At maximum dynamic pressure, the limits are about +1.7 and -2.7 deg. As the dynamic pressure is reduced, the limits increase in magnitude until, at the minimum value, they become about +7 and -10 deg. Since the model will be pitched about its base, the available magnetic restraint may be reduced about 10 percent at -10 deg because the magnetic mass will be slightly further away from the lift magnets unless this reduction is compensated by the influence of the drag magnet (Ref. 7).

Typical axial forces that may be expected are shown in Figs. 9 and 10.

SECTION VI
FUTURE CAPABILITIES

6.1 FLOW VISUALIZATION

Existing schlieren-quality windows, now used with Tunnel E, will be used also with the redesigned test section. Also existing is a simple direct shadowgraph system which can be used for visualizing the flow around the model in the downstream position or in the wake as the model is moved upstream. This existing system is limited in sensitivity, however, and a more highly sensitive system is believed to be necessary to observe the flow details in the wake region. Under consideration is a conventional single-pass schlieren or parallel-beam refocused shadowgraph system utilizing a 70-mm camera together with a spark light source of about one-microsecond duration. High-speed 16-mm camera equipment with film speed up to 7000 frames/sec is available for motion pictures using a continuous light source, or about 1000 frames/sec using a repetitive spark light source.

6.2 MACH NUMBER RANGE EXTENSION

The Mach number range of the redesigned Tunnel E can be extended down to Mach number 5 and up to Mach number 10 with additional throats and with some internal modifications to the heater in order to obtain the temperature required for Mach 10, liquefaction free flow.

By some further modifications the capability can be extended to cover a range of Mach numbers from 2 to 5. A Mach number range from 5 to 10 would require the modifications mentioned above. A Mach number range from 2 to 5 would require a new stilling chamber, additional throats, and nozzle.

6.3 MAGNETIC SUPPORT IMPROVEMENTS

The lift electromagnets have the disadvantage of overheating when operated for long periods of time under heavy load conditions and also impose a limit on the amount of lift force than can be counteracted. Future improvements will include the modification of the existing lift coils to low-voltage, high-current, water-cooled coils having at least two times the lifting capability. This change will also necessitate the use of new low-voltage, high-current SCR power amplifiers.

6.4 SPECIAL TEST INSTRUMENTATION

In order to more fully utilize the capabilities of the magnetically equipped tunnel, the following developments are envisaged:

1. Density, Rotational, and Vibrational Temperature Measurement:

   Measurement of density, rotational, and vibrational temperature utilizing Raman scattering effects from laser radiation will be investigated. This method is preferred over others considered because of the density levels and magnetic fields associated with Tunnel E.

2. Telemetry Apparatus and Techniques:

   Techniques will be developed and apparatus procured for telemetry of pressure and heat transfer rate data from magnetically suspended models. Initial work will be on a four-channel telemeter.

3. Hot Film Measurements:

   Wake surveys will be made using existing hot wire/film equipment to gain operation and interpretation experience.

4. Gas Concentration Probe Apparatus and Techniques:

   Gas sampling apparatus will be fabricated, calibrated, and evaluated for use in hypersonic wakes. The technical literature suggests that the performance of this type of probe will be affected by the relative molecular weights of the wake air and the foreign gas. Centrifugal forces at the probe entrance will turn the lighter gas around the probe.

5. Cone Static Pressure Probe Techniques:

   Small, sharp cone, static pressure probes will be fabricated and tested at combinations of Mach and Reynolds numbers. Based upon calibration tests, a viscous correction will be determined for the cone probe surface pressure. These results will be used in later computer programs which compute wake flow properties from measurements of cone static pressures, pitot pressure, and total temperature.

REFERENCES

1. Test Facilities Handbook (6th Edition). "von Kármán Gas Dynamics Facility, Vol. 4." Arnold Engineering Development Center, November 1966.

2. Sivells, James C. "Aerodynamic Design and Calibration of the VKF 50-Inch Hypersonic Wind Tunnels." AEDC-TDR-62-230 (AD299774), March 1963.

3. Hall, I. M. "Transonic Flow in Two-Dimensional and Axially-Symmetric Nozzles." A.R.C. 23, 347, December 1961.

4. Bailey, A. B. "Turbulent Wake and Shock Shape of Hypervelocity Spheres." AEDC-TR-66-32 (AD484821), July 1966.

5. Bailey, A. B. "Effect of Unit Reynolds Number on Transition in the Wakes of High Speed Sharp Slender Cones." AEDC-TR-66-137 (AD486584), July 1966.

6. AGARDograph 97. "Recent Developments in Boundary Layer Research." May 1965.

7. Crain, C. D., Brown, M. D., and Cortner, A. H. "Design and Initial Calibration of a Magnetic Suspension System for Wind Tunnel Models." AEDC-TR-65-187 (AD470147), September 1965.

APPENDIX
ILLUSTRATIONS

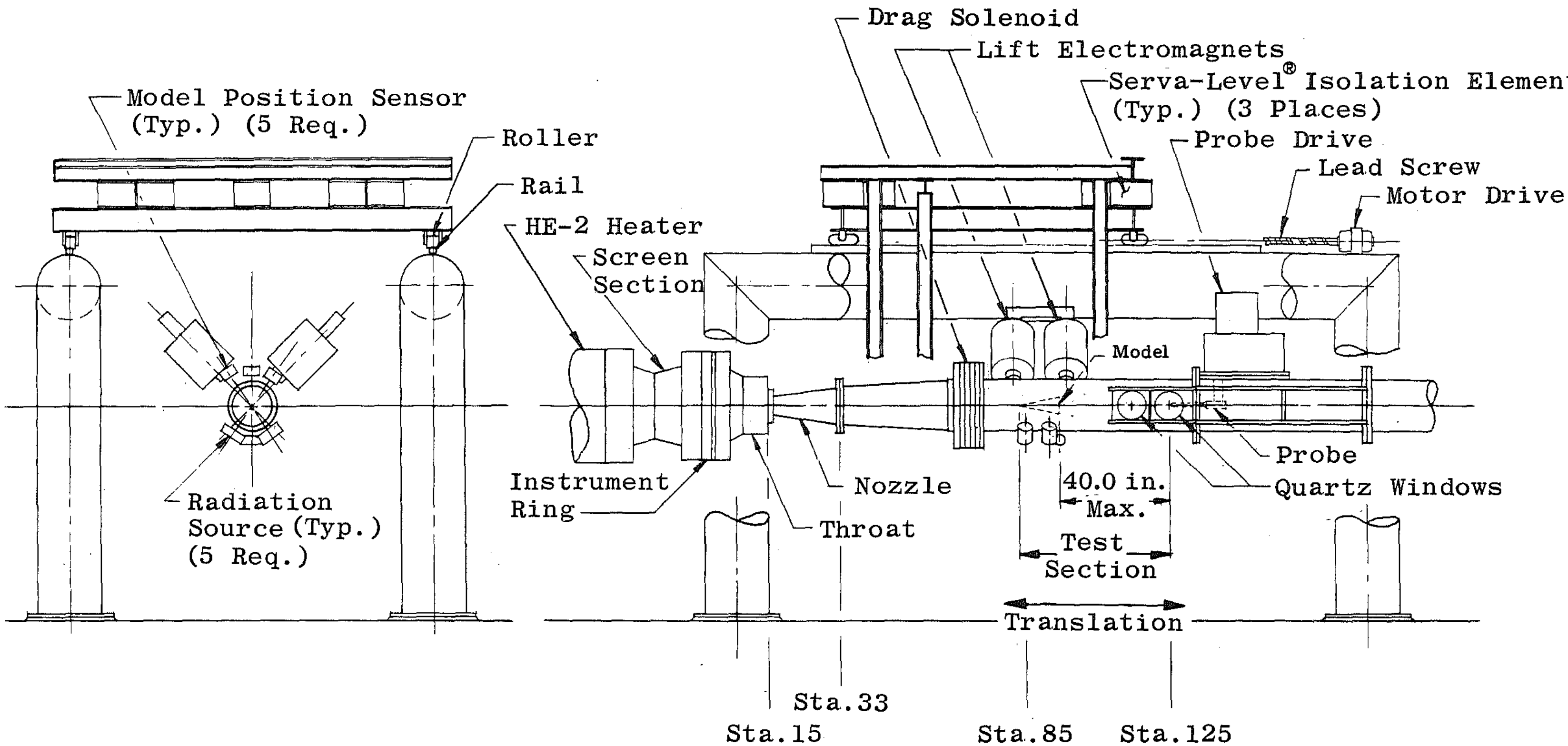

Fig. 1 Tunnel E Magnetic Suspension System

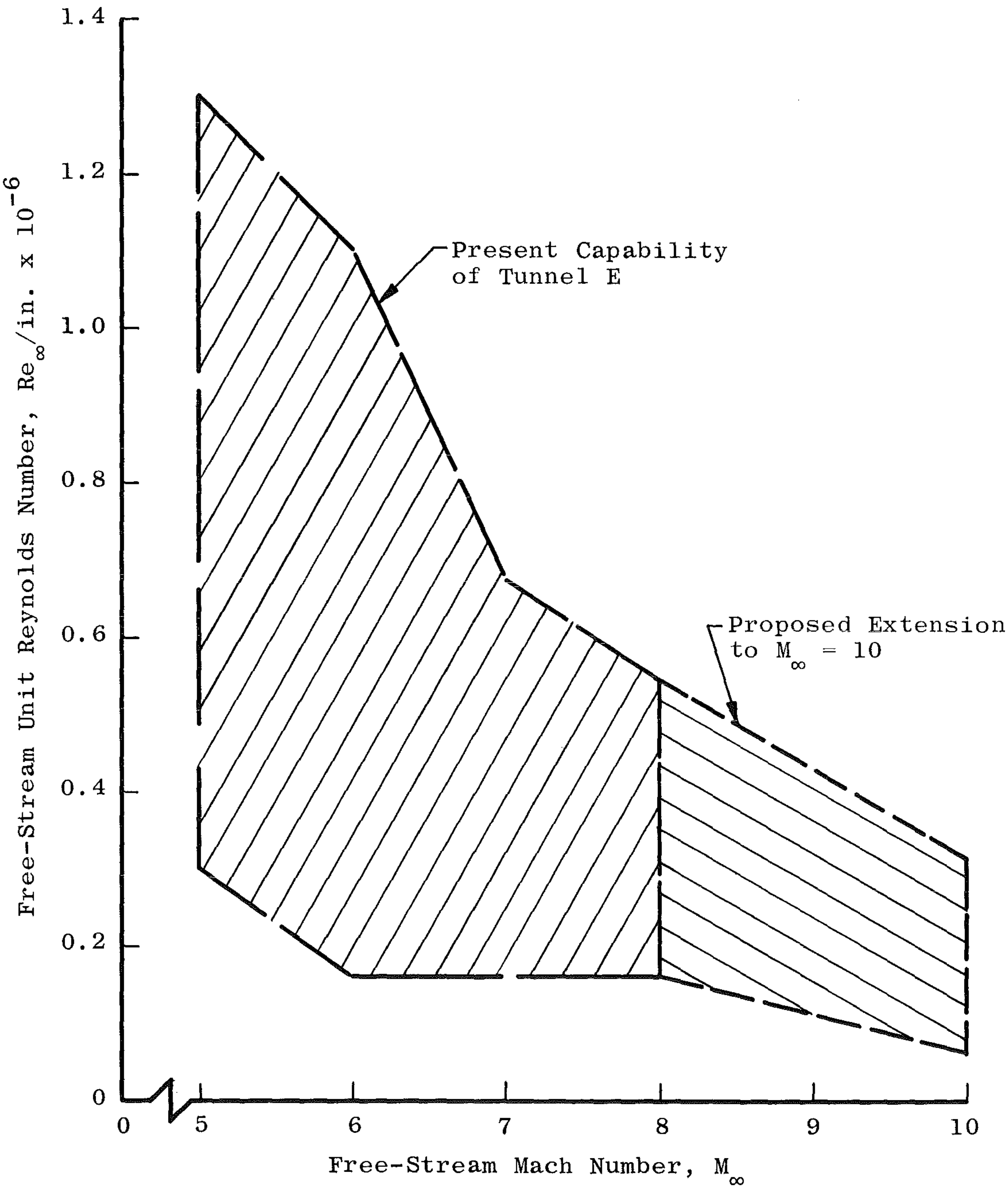

Fig. 2 Reynolds Number versus Mach Number

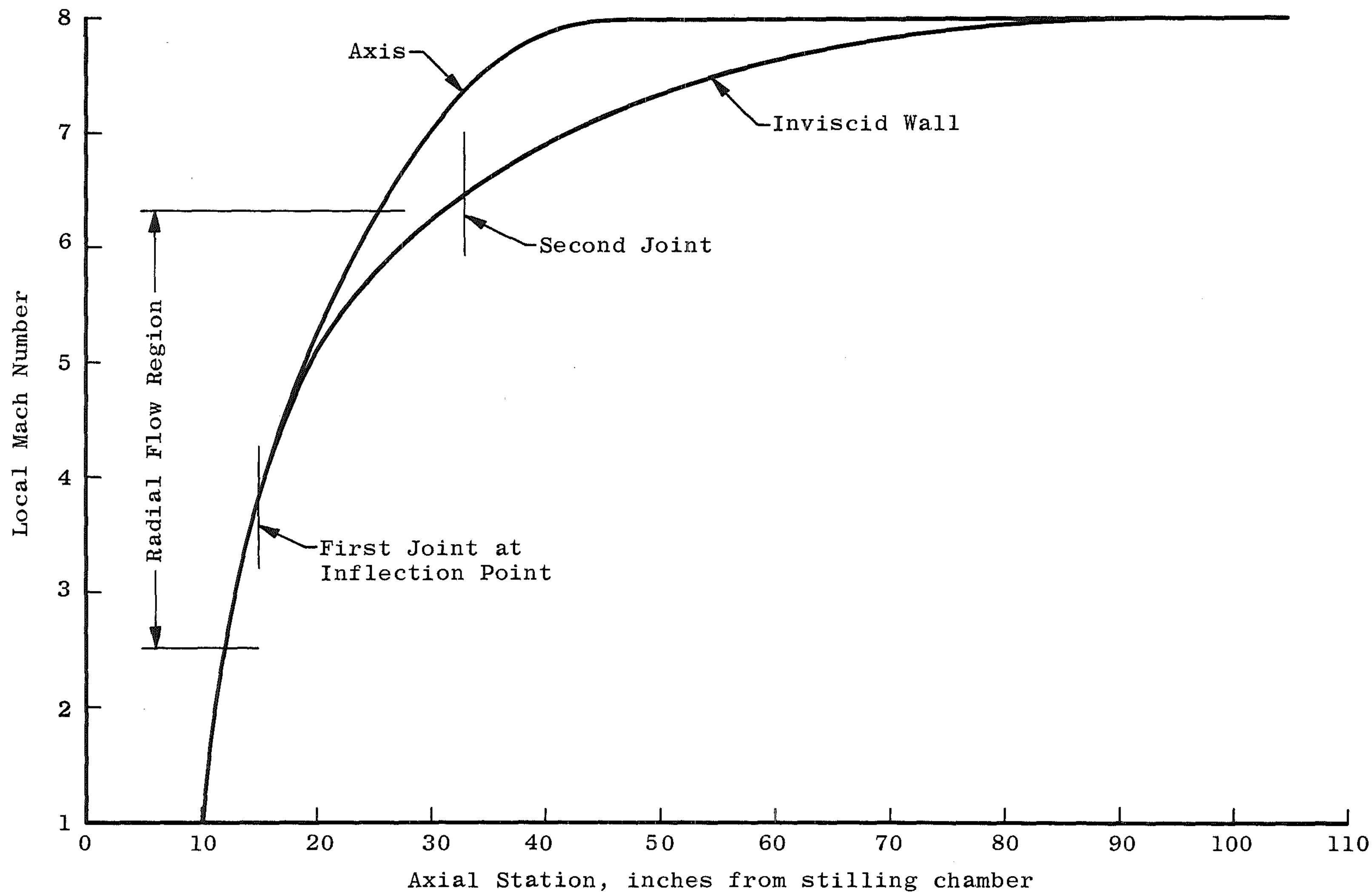

Fig. 3 Mach Number Distribution in Nozzle

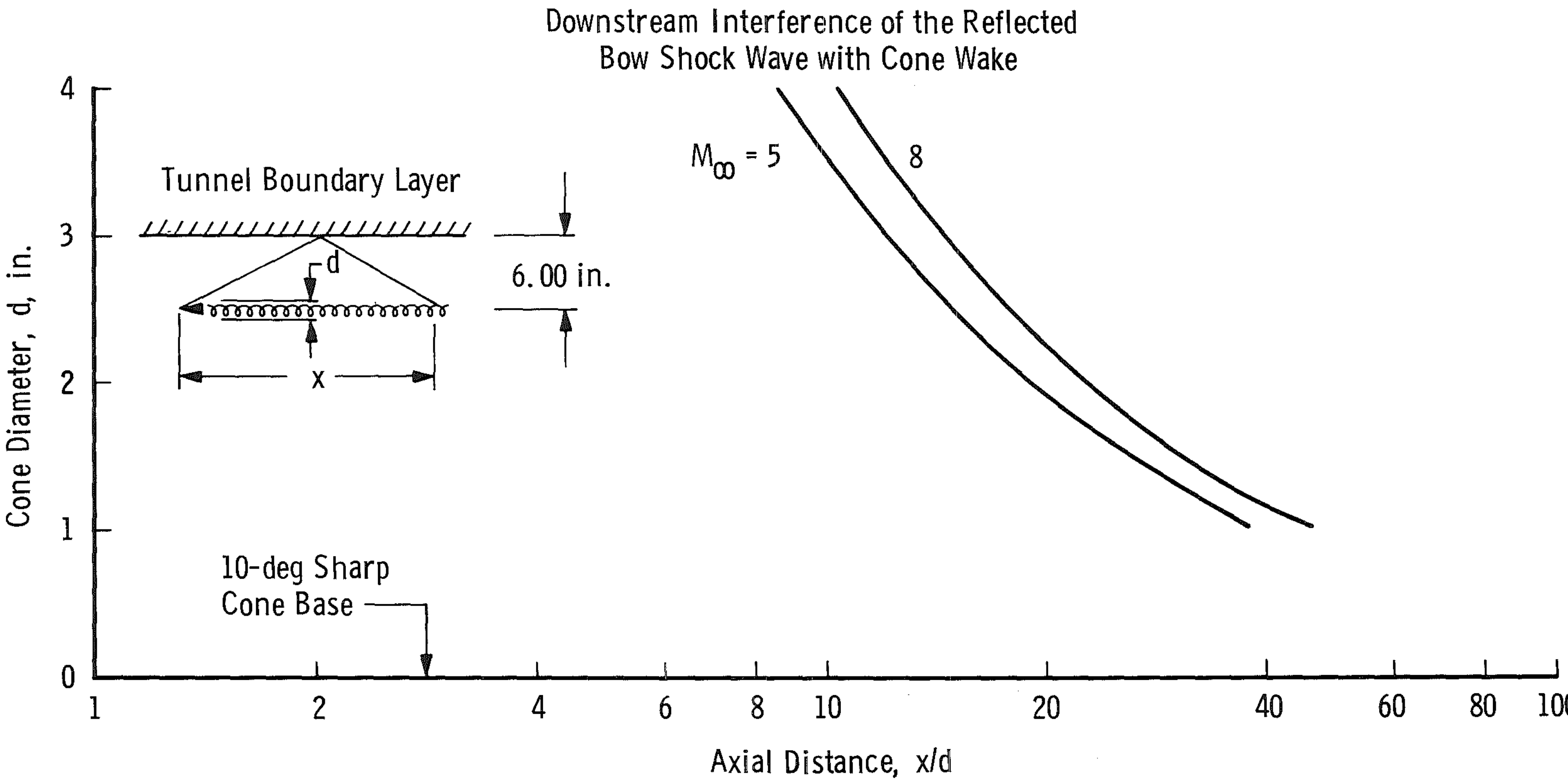

Fig. 4 Cone Wake Interference at Mach 8 and Mach 5

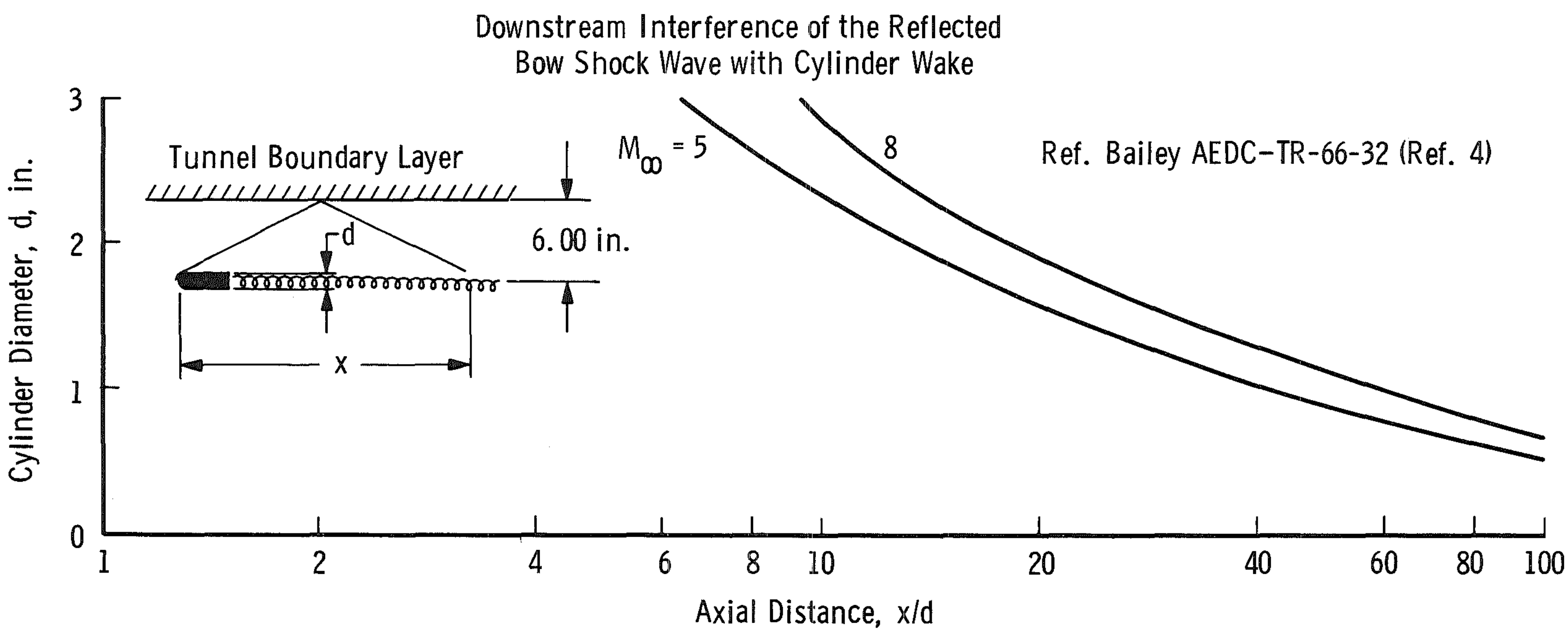

Fig. 5 Hemisphere-Nosed Cylinder Wake Interference at Mach 8 and Mach 5

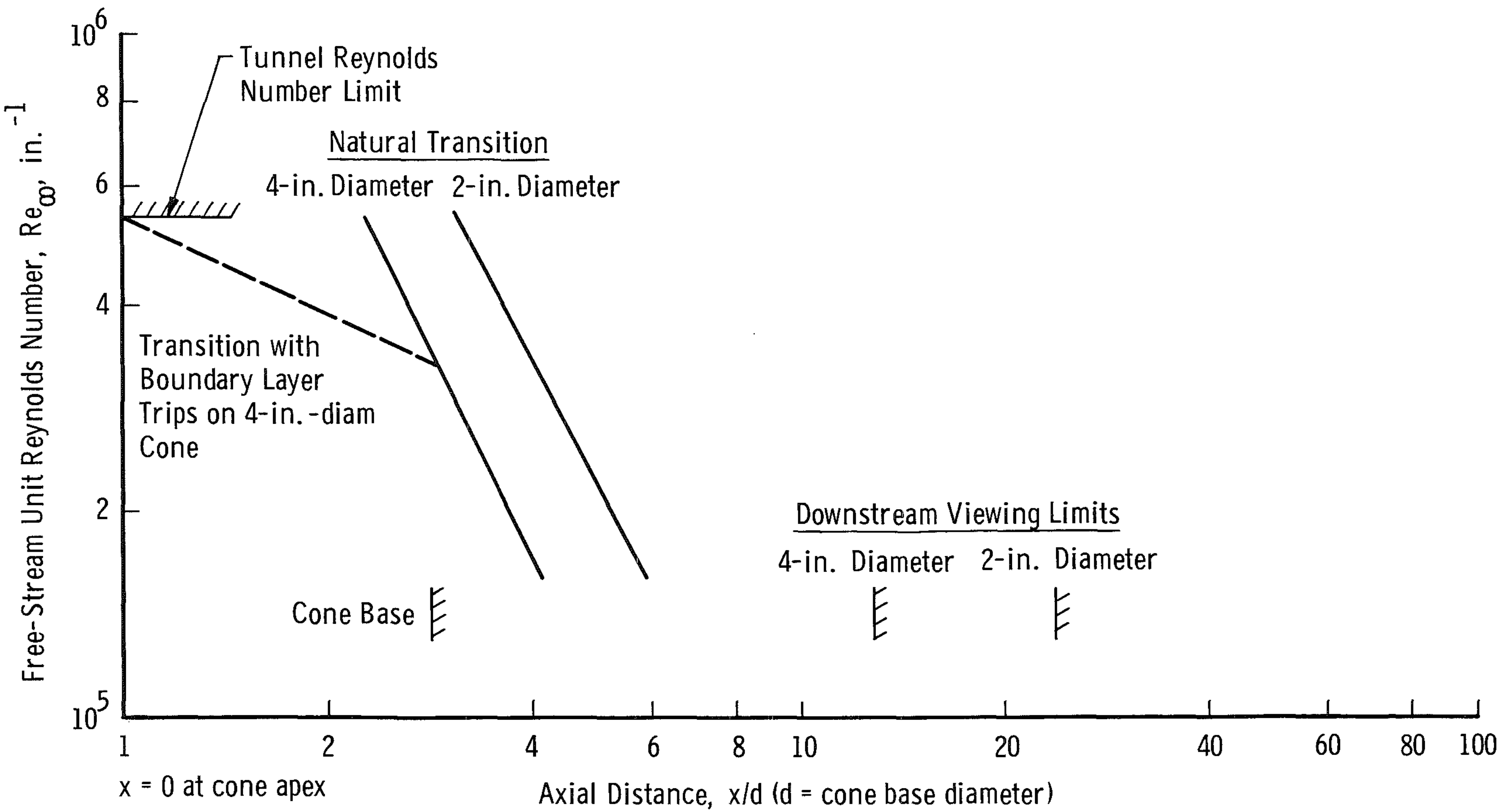

Fig. 6 Cone and Wake Transitions on a 10-deg Sharp Cone at Mach 8

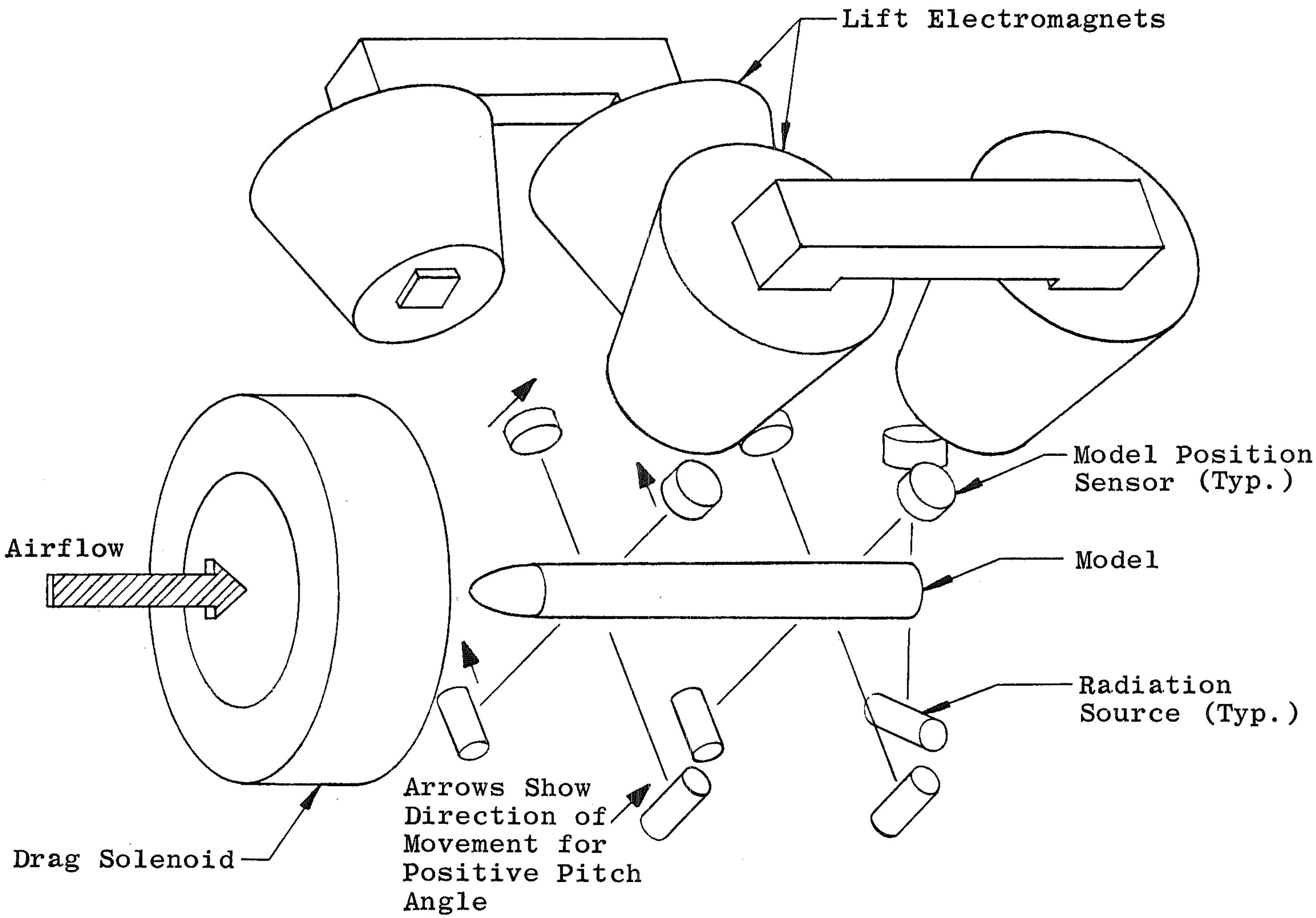

Fig. 7 Model Positioning Magnets and Position Sensing System

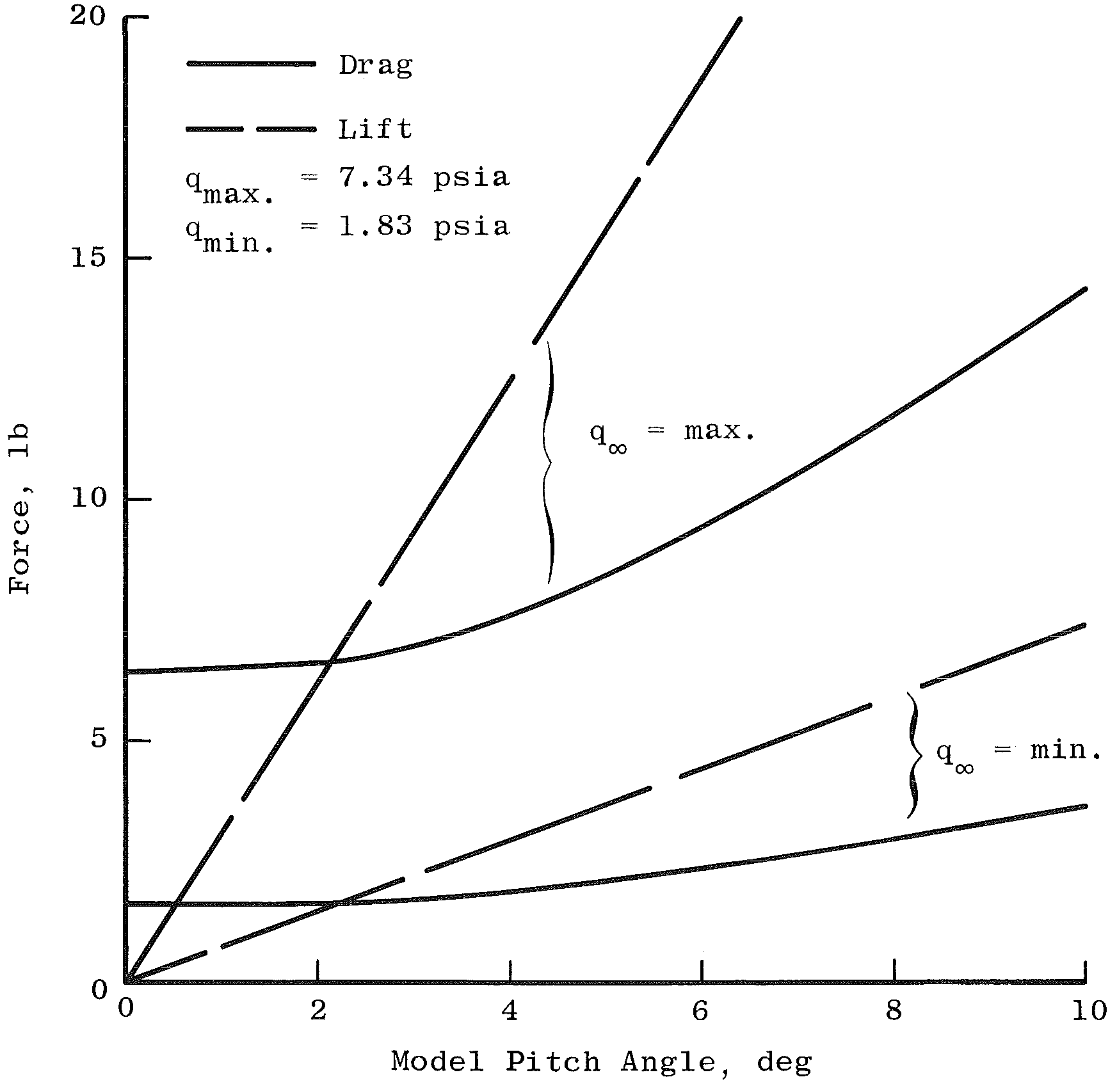

Fig. 8 Lift and Drag of a 4-in.-diam 10-deg Sharp Cone at Mach 8

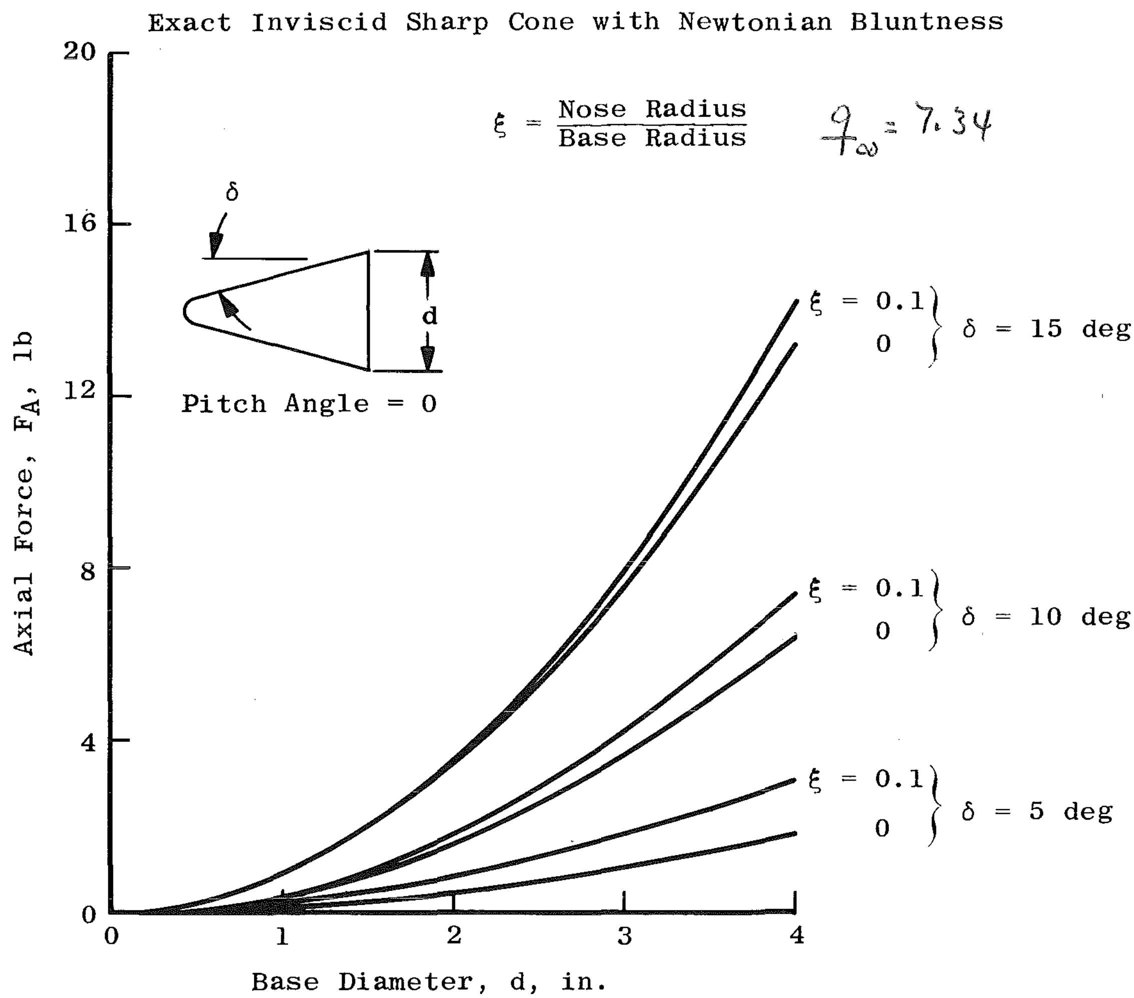

Fig. 9 Axial Force on 5-, 10-, and 15-deg Half-Angle Cones at Mach 8

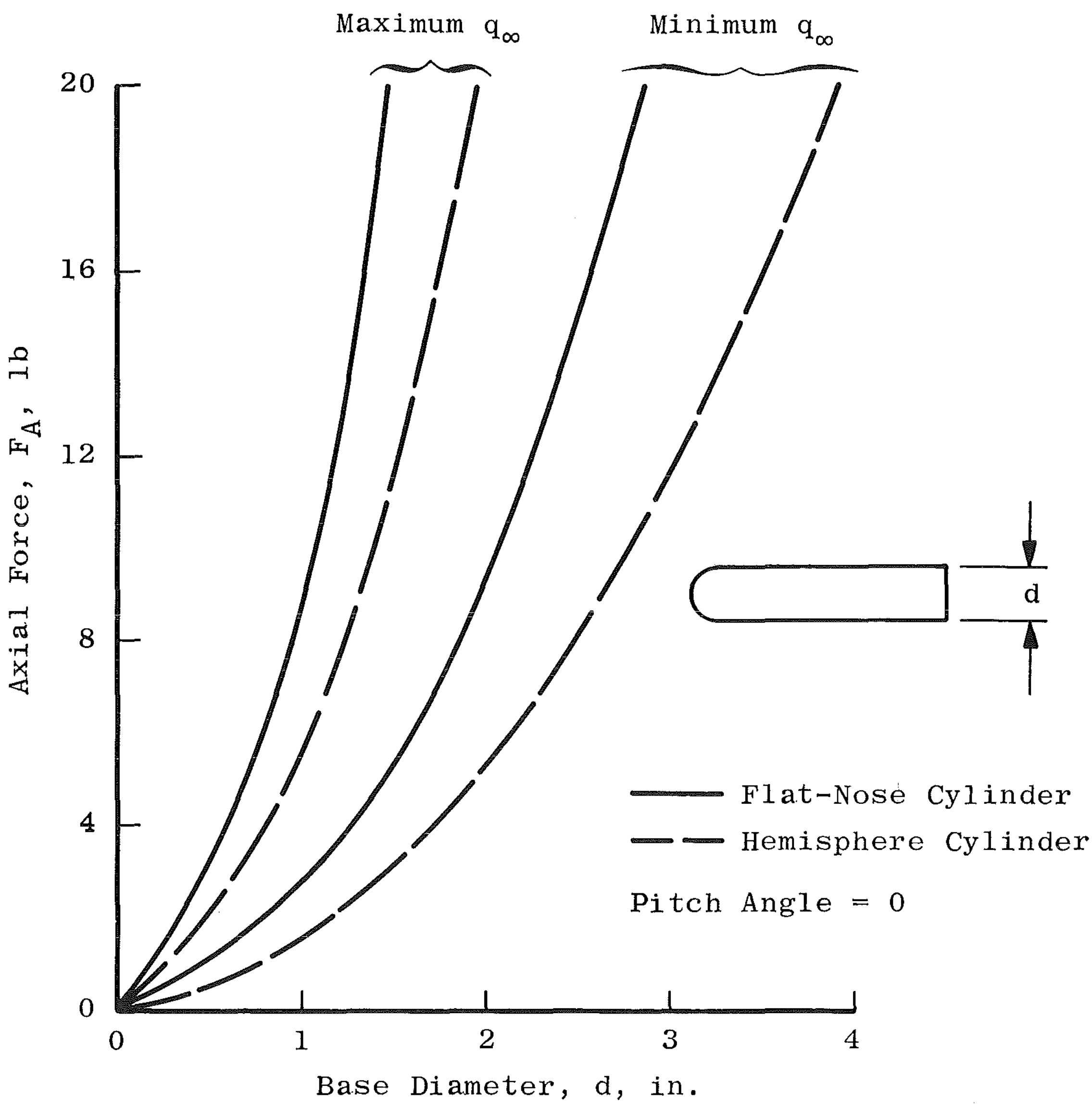

Fig. 10 Axial Force on Flat Nose and Hemispherical Cylinder at Mach 8

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Arnold Engineering Development Center ARO, Inc., Operating Contractor Arnold Air Force Station, Tennessee	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

TUNNEL E WITH MAGNETIC MODEL SUPPORT SYSTEM - BASIC CONCEPT AND INITIAL DESIGN

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

March 1967 to October 31, 1967 - Interim Report

5. AUTHOR(S) *(First name, middle initial, last name)*

J. M. Langford, ARO, Inc.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
January 1968	27	7

8a. CONTRACT OR GRANT NO. AF40(600)-1200 b. PROJECT NO. 0988 c. System 920F d.	9a. ORIGINATOR'S REPORT NUMBER(S) AEDC-TR-67-268 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* N/A

10. DISTRIBUTION STATEMENT This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Arnold Engineering Development Center (AETS), Arnold Air Force Station, Tennessee.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Available in DDC	Arnold Engineering Development Center (AETS), Air Force Systems Command, Arnold AF Station, Tenn.

13. ABSTRACT

This report discusses the addition of the existing magnetic model suspension system to the 12- by 12-in. hypersonic Tunnel E at Arnold Engineering Development Center. The addition requires an unusually long test section for studying undisturbed model wake. With the magnetic suspension system, the model can be positioned in any axial direction, and the model angle of incidence can be changed in either positive or negative direction. The proposed model positioning sensor system will consist of a gamma or X-ray source and ion detectors that will allow the model position to be controlled without need for optical ports in the tunnel wall. The instrumentation for and overall test capabilities with this magnetic suspension system in Tunnel E are discussed, and proposals for future improvements in the capabilities of the system are made.

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Arnold Engineering Development Center (AETS), Arnold Air Force Station, Tennessee.

DD FORM 1 NOV 65 1473

Security Classification

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
magnetic suspension systems						
wind tunnels, hypersonic						
detectors						
instrumentation						
wakes						

Security Classification